AD-A173 572 SPRAY CHARACTERIZATION USING PHASE ANGLE DETECTION(U) 1/1
AEROMETRICS INC MOUNTAIN VIEW CA W D BACHALO 18 JUL 86
AFOSR-TR-86-0929 F49620-84-C-0023

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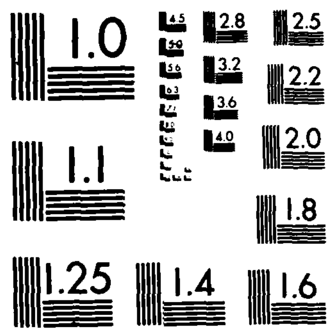

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1.0 RESEARCH OBJECTIVES

The following is an outline of the research objectives addressed in the first year of the program.

1.1 Perform a comprehensive theoretical analysis of the dual beam light scattering and phase shift phenomena produced by spherical particles. Develop the theory for decomposition of the scattering into the mechanisms of diffraction, reflection, and refraction. Generate the Mie scattering theory for dual beam light scattering and compare the results obtained from the geometrical optics theory.

1.2 Develop and conduct experiments to verify the theoretical results relevant to the phase detection method. Establish the range of parametric conditions beyond which measurement ambiguities might occur.

1.3 Conduct experiments using monodisperse drop streams, simulated sprays (monodisperse streams in the presence of sprays), and various sprays. Investigate marginal angles of light scatter detection between reflection and refraction.

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1.4 Experimentally determine the characteristic dimensions of the sample volume and how the sample volume changes with the various optical parameters and drop size.

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1.5 Generate a theoretical description of the sample volume size as a function of the drop size assuming a Gaussian beam intensity distribution.

1.6 Perform analyses and conduct tests to determine the droplet number density limitations and the occurrence of coincidence errors.

1.7 Investigate the quantum efficiency and noise characteristics of solid state detectors and photomultipliers to establish the size range achievable by single particle counter instruments. Evaluate the effects of photocathode saturation, dynode chain design, and shot noise.

1.8 Perform experiments using off-axis backscatter light detection as a means of eliminating the sensitivity of the size determination upon the droplet refractive index.

1.9 Conduct studies with the beams transmitted through flames to determine the relative effects that the combusting flow fields with a range of turbulence levels may have upon the measurements of the size and velocity of the droplets and gas phase motion. Measure monodisperse streams of droplets through flames and observe the effects, if any, of the turbulence induced fringe motion.

1.10 Review the data processing methods and define the drop size distributions and classifications according to these statistical analyses. Provide both temporal and spatial size distributions.

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1.11 Obtain detailed measurements on sprays at controlled conditions and make comparisons to other methods.

1.12 Investigate the potential of measuring the gas phase velocities based on seed particles in the presence of typical sprays.

1.13 Perform preliminary evaluations of the method in turbulent spray flames. Make comparisons to burning and nonburning measurements.

STATUS OF THE RESEARCH EFFORT

An optical method for obtaining simultaneous particle size and velocity measurements in sprays, turbulent two-phase flows, and other fluid dynamic processes has been sought for well over a decade. The Phase Doppler method, which was the subject of this investigation, has the desired characteristics and capabilities needed in obtaining these data. Size and velocity information are obtained from the dynamic measurements of the fringe pattern formed by the light scattered from two intersecting laser beams, figure 1. While the temporal frequency of scattered interference fringe pattern provides velocity information (Doppler difference frequency), the spatial frequency is a function of the particle size. Pairs of detectors are used to measure spacing of the scattered interference fringe pattern in the plane of the receiver. These detectors produce Doppler burst signals that are shifted in phase. The phase shift between the signals is proportional to the detector separations, and is linearly related to the particle size.

In the first year of the program, the theoretical descriptions of the dual beam light scattering were reviewed and extended to include the effects of the relevant optical parameters. The geometrical optics were used to describe the light scattering phenomena for spheres larger than about 3 microns. Possible problems that can occur due to combined light scattering from both refraction and reflection are most conveniently investigated using the geometrical optics theory.

When using Gaussian beam intensities to measure drops on the order of the focused beam diameter, drops passing on certain trajectories will scatter light intensities of similar magnitude by the mechanisms of reflection and refraction. Under such circumstances, the interference fringe

pattern produced by the scattered light will no longer be sinusoidal, but will consist of a combination of six interference fringe patterns. These fringe patterns will have different amplitudes, spatial frequencies, and temporal frequencies that are the same but cause the fringe patterns to move in opposite directions. Significant efforts were expended on the analysis of this potential problem. An obvious solution was to maintain focused beam diameter at 2 to 3 times the largest drop size. Selecting the incident beam polarization and light scatter detection angle can also be used to increase the difference in scattering amplitudes from refraction versus reflection.

The Lorenz-Mie theory was developed to describe the light scattering and interference for particles of arbitrary size. Unfortunately, the Mie theory has boundary conditions for uniform illumination of the drop. With the high number density requirements on the instrument, the Gaussian beams cannot always be made large enough to approximate this condition. Thus, further development of the exact light scattering theory to handle Gaussian beams will be undertaken. Further analyses were performed on the signal detection and processing schemes to determine how the nonsinusoidal interference fringe pattern would affect the measurement accuracy. It was found that judicious selection of the detector spacings and the implementation of signal discrimination logic could suppress, but not completely eliminate the problem. A sacrifice of measurement range at a single optical setting was required to completely eliminate serious measurement errors. That is, since the fringes produced by reflection move in the opposite direction to those produced by refraction, the phase is measured approximately as $360-\Phi$ instead of Φ. Rather than allow large errors, the upper 30% of the range was excluded. This did not result in any serious limitation on the overall performance of the instrument since ranges have a large overlap.

Numerous experiments were conducted using monodispersed drop streams to identify the above problem, investigate the effect of changing optical parameters, and to test the system after optimization. Drops with a range of diameter ratios (drop size to beam diameter) were directed on all trajectories through the beams. Modifications were made to the optics and processing logic such that significant measurement errors did not occur as a result of multi-component light scatter detection. Dye was also added to the monodispersed drops to partially extinguish the refracted light and thus, exacerbate the problem. These experiments demonstrated that with proper optical design, such measurement errors can be avoided. Only after using a high concentration of dye (90%) to absorb the transmitted light, did the reflected scattering dominate. Overall, the experiments with the monodispersed streams traversed through all trajectories were considered definitive in the evaluation of this error source.

A related source of error can occur when particles pass through the measurement volume in the direction opposite to the expected direction. This occurs, for example, at the edge of sprays or within the spray cone wherein small drops recirculate. A drop moving in the reverse direction may be measured as $360-\Phi$ instead of Φ, resulting in a very large error. In order to avoid this, it was recognized that frequency shifting was necessary for most applications of this method. This capability was incorporated in the instrument.

The introduction of frequency shifting provided all of the advantages realized with a conventional laser Doppler velocimeter. Frequency shifting serves to compress the frequency bandwidth, resolve reversed flow velocities, remove biasing due to large angles of trajectory, and allows the measurement of the cross-stream velocities. Measurements of the drop size-velocity correlations, figure 2, for several axial stations illustrate the importance of these measurement capabilities.

Significant reversed flow velocities were detected near the exit plane of the pressure atomizer. Without frequency shifting, these reversed trajectories would have produced erroneous size measurements indicating very large drops. Figure 3 shows the variation of the angle of trajectory with drop size. The convection and trajectory characteristics of the spray affect the downstream variations of the drop size distributions and consequently, the process associated with the spray.

As a further evaluation of the method while operating in realistic environments, comparisons of spray measurements were made with the data obtained by other methods. Since there is no definitive means for obtaining spray characterization, such comparisons remain as the only recourse for evaluating new methods. Figure 4 is an example of a comparison with the Fraunhofer diffraction method. Corresponding particle number densities obtained from extinction measurements and the Lambert-Beer Law were compared with results obtained with the Phase Doppler method, figure 5. These latter results serve to verify the accuracy of the method for directly measuring the probe volume cross section, developed in the early stage of this research program.

This two-year research program has led to the successful development of an instrument for spray and two-phase turbulent flow research. The present research program allowed the thorough investigation of all aspects of the measurement requirements to ensure that reliable data could be obtained with the instrument.

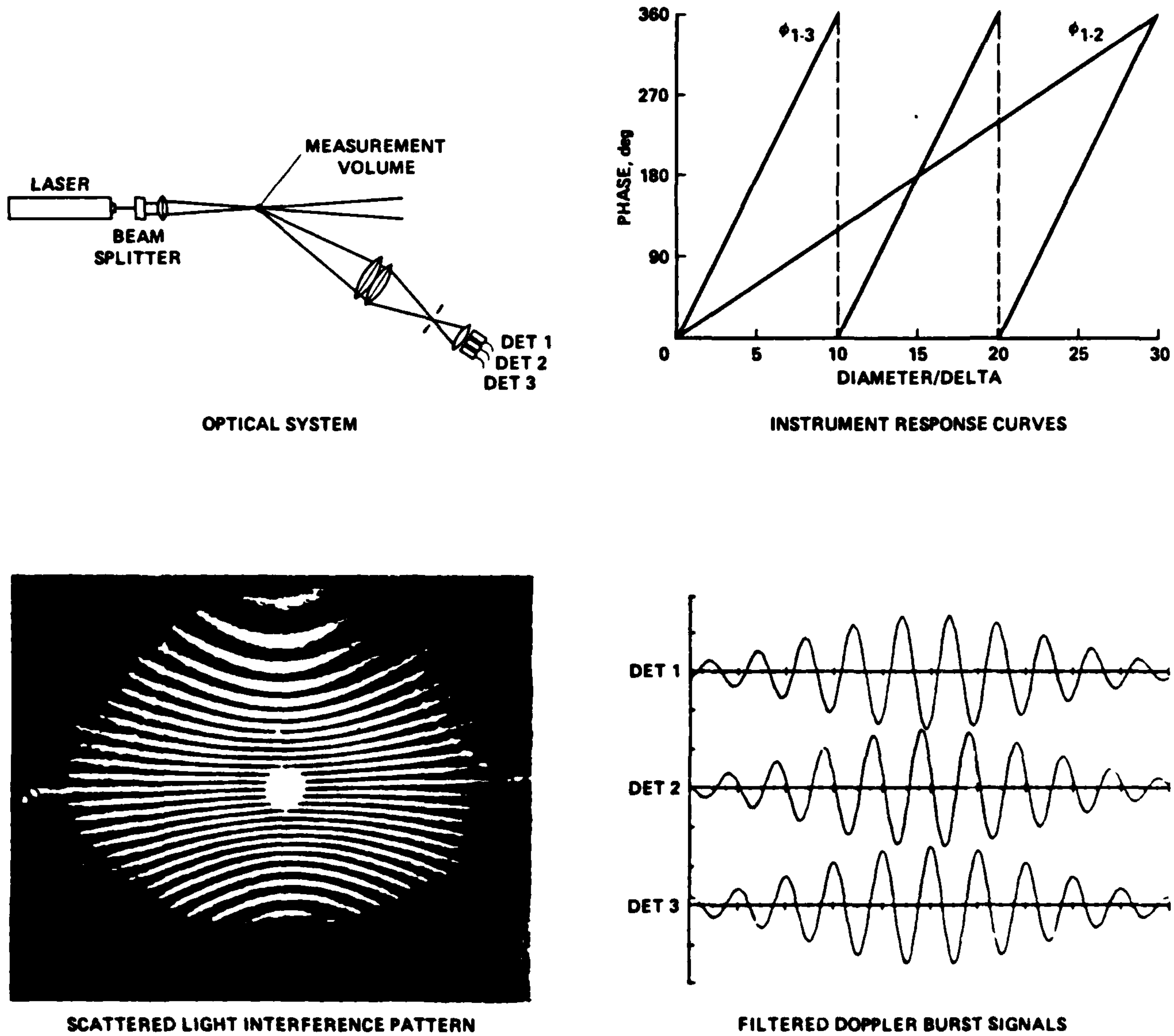


Figure 1. Schematic of the Phase/Doppler Spray Analyzer Technique.

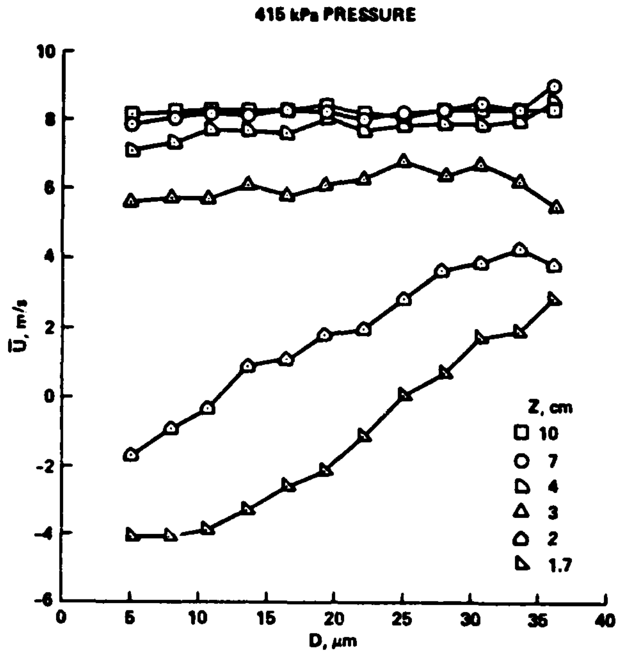
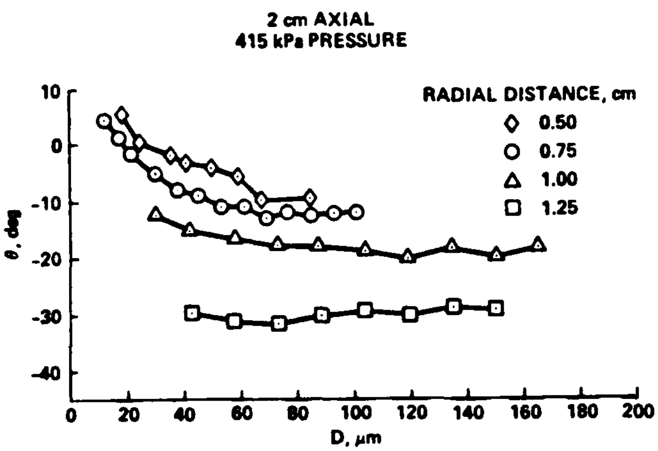
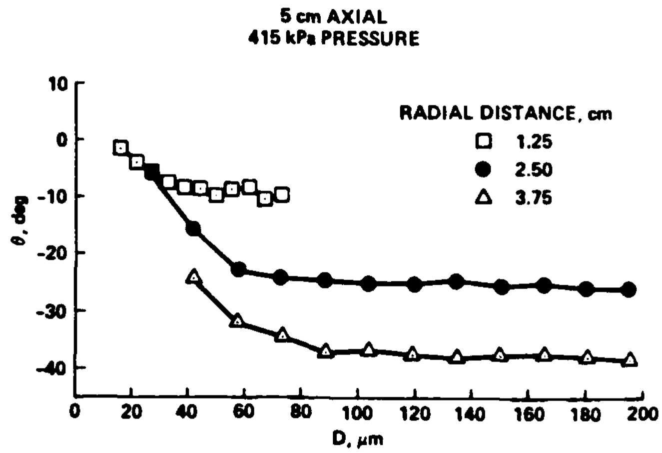


Figure 2. Axial Development of the Size-Velocity Correlation



3a. Z = 2cm



3b. Z = 5cm

Figure 3. Drop Angle of Trajectory Versus Size

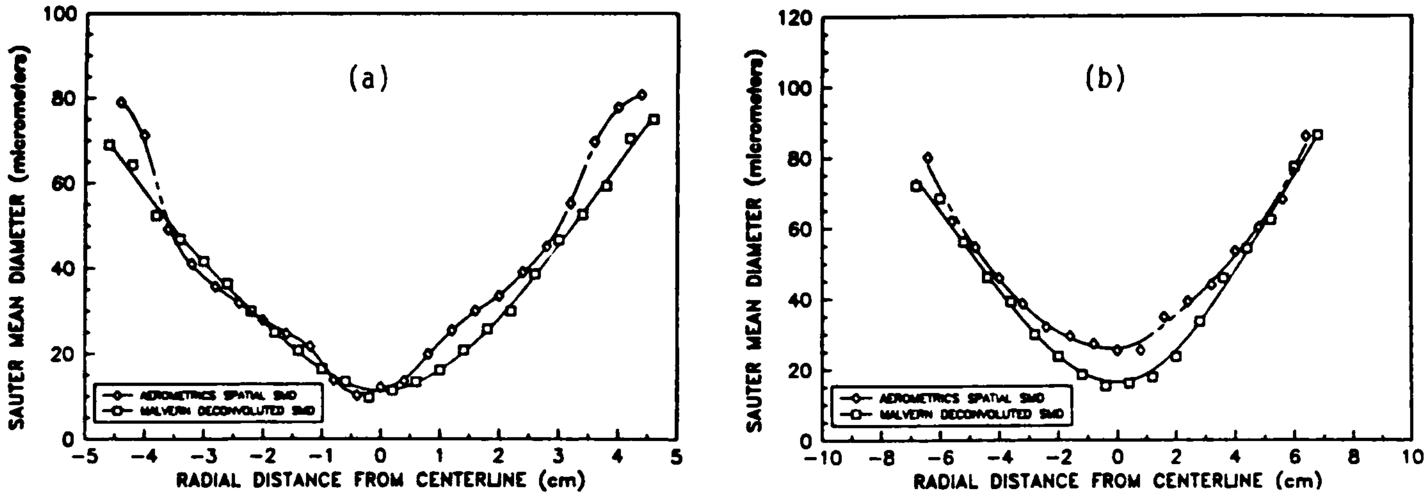


Figure 4. Comparison of SMD's Measured at a Point by Aerometrics Phase/Doppler Instrument and by Malvern Laser-Diffraction Instrument (after deconvolution) for a Fuel Pressure Drop of 689 kPa and an Axial Distance of (a) 50mm, (b) 100mm.

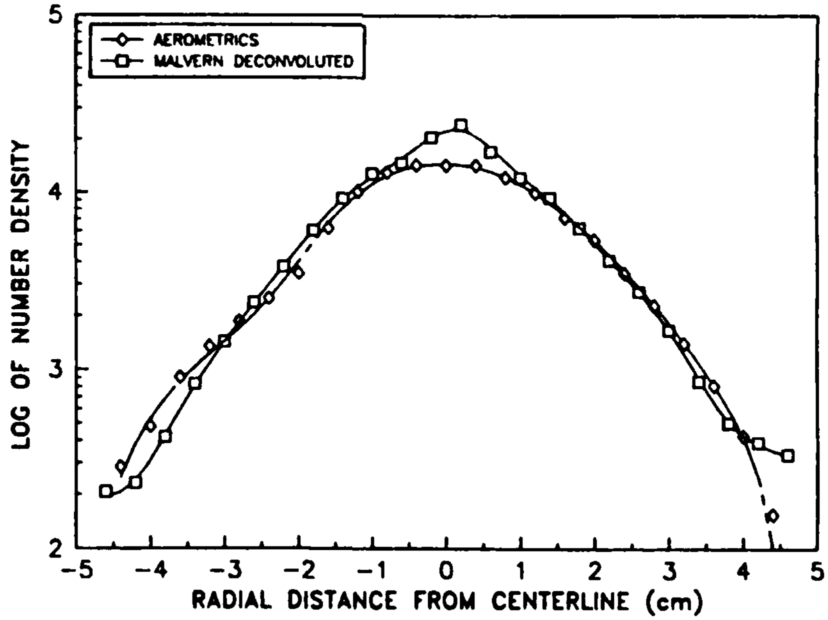


Figure 5. Comparison of Number Densities at a Point by Aerometrics Phase/Doppler Instrument and by Malvern Laser-Diffraction Instrument (after deconvolution) at an Axial Distance of 50mm and a Fuel Pressure Drop of 345 kPa.

PUBLICATIONS

1. W. D. Bachalo and M. J. Houser, "Phase/Doppler Spray Analyzer for Simultaneous Measurements of Drop Size and Velocity Distributions," Optical Engineering, Vol. 23, No. 5, 1984.

2. W. D. Bachalo and M. J. Houser, "Development of the Phase/Doppler Spray Analyzer for Drop Size and Velocity Characterizations," to be submitted to AIAA Journal.

3. W. D. Bachalo and M. J. Houser, "Experiments in Polydisperse Two-Phase Turbulent Flows," Proceedings of the International Symposium on Laser Anemometry, FED-Vol. 33, Editors: A. Dybbs and P. A. Pfund.

4. W. D. Bachalo and M. J. Houser, "Particle Dynamics Measurements from Light Scattering Interferometry," to be submitted to Applied Optics.

5. W. D. Bachalo and M. J. Houser, "Spray Drop Size and Velocity Measurements Using the Phase/Doppler Particle Analyzer," International Journal of Turbo and Jet-Engines, Vol. 3, No. 3, 1986.

6. M. J. Houser and W. D. Bachalo, "Extension of the Phase/Doppler Particle Analyzer to Submicron Particle Measurments," Proceedings of SPIE, Vol. 573, Aug. 1985.

7. W. D. Bachalo, "Characteristics of Light Scattering Interferometry Using Gaussian Beams," to be submitted to Applied Optics.

8. W. D. Bachalo, M. J. Houser, and J. N. Smith, "Evolutionary Behavior of Sprays Produced by Pressure Atomizers," to be submitted to AIAA Journal.

INTERACTIONS

1. "Analysis and Testing of a New Method for Drop Size and Velocity Measurements Using Laser Light Scatter Interferometry," Conference on Combustion Fundamentals Research, NASA Lewis Research Center, NASA Conference Publication 2309, April 16-18, 1984.

2. "Drop Size and Velocity Distributions from Measurements of Scattered Light," Carnegie-Mellon University Short Course entitled, "Particle Size and Velocity Instrumentation for Spray Analysis," May 1-2, 1984.

3. "Development of the Phase/Doppler Spray Analyzer for Liquid Drop Size and Velocity Characterizations," presented at AIAA/SAE/ASME 20th Joint Propulsion Conference, June 11-13, 1984, Cincinatti, Ohio.

4. "Development and Application of Optical Diagnostics for Atomization and Turbulent Two-Phase Flow Research," Invited Speaker, Eastern States Section of the Combustion Institute, December 3-5, 1984, Clearwater Beach, Florida.

5. "Drop Size and Velocity Distributions from the Measurements of Scattered Light," Workshop on Laser Velocimetry, March 11-15, 1985, University of Connecticut, Storrs, Connecticut.

6. "Spray Measurements: Methods and Applications," AFOSR/ARO Specialists Meeting on Atomization and Nondilute Sprays, Sandia Combustion Research Facility, Livermore, California, March 20, 1985.

7. "Spray Drop Size and Velocity Measurements Using the Phase/Doppler Particle Analyzer," presented International Conference on Liquid Atomization and Spray Systems, Imperial College, London, July 1985.

8. "Experiments in Polydisperse Two-Phase Turbulent Flows", presented ASME Winter Annual Meeting, Miami, November 1985.

9. "Evolutionary Behavior of Sprays Produced by Pressure Atomizers," presented AIAA Aerospace Sciences Meeting, Paper No. 86-0296, Reno, January 1986.

10. "Measurements of Drop Dynamics and Mass Flux in Sprays," presented Central States Meeting, Combustion Institute, NASA Lewis, May 1986.

11. Participant, NASA Lewis Droplet Technology Workshop.

12. "Evaluation of a Phase Doppler Particle Analyzer for Measuring Dense Sprays from a Gas Turbine Fuel Injector," AIAA-86-1532, presented AIAA/ASME/SAE/ASEE 22nd Joint Propulsion Conference, Huntsville, Alabama, June 1986.

13. "An Instrument for Two-Component Velocity and Particle Size Measurement," presented Third International Symposium on Applications of Laser Anemometry to Fluid Mechanics, Lisbon, Portugal, July 1986.

14. "Spray Drop Size and Velocity Characterizations," presented Spray Technology Workshop, Imperial Chemicals Industries, Berkshire, U.K., July 1986.

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ABSTRACT

An innovative method for measuring the particle size and velocity, simultaneously using the Doppler difference frequency and the phase shift of the scattered light was derived, analyzed, and evaluated experimentally. Initially, the theoretical analysis of the dual beam laser light scattering phenomena were performed using simple geometrical optics theory. This approach allowed ready insight of the complex scattering phenomena associated with the method. In particular, the difficulties that may occur when scattering amplitudes due to reflection and refraction are of similar order of magnitude were easily investigated. Numerous experiments using monodispersed drop streams were used to assess the measurement accuracy and possible errors produced by the mixed scattering components. The Lorenz-Mie theory was derived for the dual beam scattering and used to evaluate the measurement capability for particles on the order of a micron in diameter. Experiments were conducted using polytyrene latex spheres to demonstrate that particles as small as 0.5 micron can be measured. A method was also derived for automatically measuring the sample volume for each size class. This information was then used to correct for the sample volume bias. Absolute measurements of the sampling cross-section were used to obtain mass flux and particle number density measurements in sprays. Comparisons with sampling probe data, nozzle flowrate, and light extinction measurements were in good agreement. Incorporation of frequency shifting into the system allowed the measurement of the drop angle of trajectory and reversed flow velocity components, while eliminating possible sizing errors produced by reversed flows. Successful measurements have been made of drop size and velocity in turbulent spray flames with swirl and recirculation.

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